Automotive Propulsion Materials

Effect of Thermal Cycling on the Properties of NdFeB Permanent Magnets

Background

New technologies, such as permanent magnets for motors, sensors, and control systems, are necessary for achieving FreedomCAR and Vehicle Technologies Program goals. Such magnets will have to operate reliably over a wide range of temperatures and be resistant to thermal cycling.

To support those developmental efforts, ORNL built an experimental test facility to assess the effect of temperature and thermal cycling on the magnetic and mechanical properties of permanent magnets.

Technology

The experimental test facility developed at ORNL consists of an environmental chamber capable of operating between -100°C and 300°C. Test temperatures below ambient temperature are attained by dispersing liquid nitrogen using compressed air, while higher temperatures can be attained by using compressed air and cartridge heaters. The interior of the $61 \times 30 \times 30$ cm^3 chamber is lined with insulation to ensure uniform temperature distribution.

A computer-based system was assembled for data acquisition and control. This system includes a personal computer, a high-speed A/D data acquisition card, customized software written with LabView® and a digital temperature controller. Inside the environmental chamber an array of sixteen 6.5-mm diameter rods is mounted onto a frame that is connected to a pneumatic actuator. The permanent magnets under evaluation, which are shaped in the form of prismatic beams, are mounted using a removable adhesive at various locations along the rods. A series of coils, which are concentric to the rods, were placed at fixed locations.

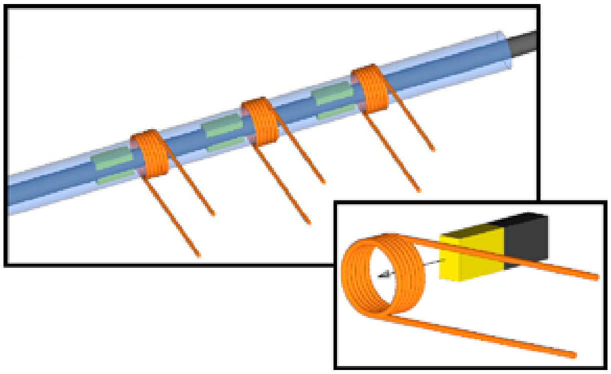

Figure 1. *Faraday's law is used to determine the magnetic strength of permanent magnets.*

Benefits

- A test facility was developed to help designers of automotive components that incorporate permanent magnets to determine how the properties of magnets change as a function of temperature and thermal cycling.
- This facility is available to industry and academic institutions as part of the High Temperature Materials User Program.

When the pneumatic actuator is activated, the rods, and the magnets, slide through the coils, inducing in turn a voltage across the terminals of the coils. According to Faraday's law the voltage induced in the coil is proportional to the change in the magnetic flux through the coil, according to:

$$V = -\frac{d\Phi}{dt} = -\mathrm{N}\,\mathrm{A}\,\frac{dB}{dt}$$

where B(t) is the magnetic field of the magnet, N is the number of turns in the coil, and A is the crosssectional area of the coil.

The voltage induced is recorded as a function of temperature and the number of thermal cycles. Therefore, by measuring the voltage it is possible to determine if any changes have occurred in the magnetic strength of the magnet under evaluation.

After a predetermined number of thermal cycles, test specimens are removed from the environmental chamber and evaluated in a fourpoint bending to assess the effect of thermal cycling on their mechanical strength.

Status

It has been found that the magnetic strength of bonded and sintered permanent NdFeB magnets decreases linearly with temperature and that at a given temperature, it decreases exponentially with the number of thermal cycles.

It was also found that sintered NdFeB magnets were 10 times stronger than bonded NdFeB magnets and that the flexural strength of both decreased with the number of thermal cycles.

Figure 2. *Experimental test facility to evaluate the thermal cycling resistance of permanent magnets.*

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